Predictability of the North Atlantic Oscillation on Intraseasonal Time Scales

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LONG-TERM GOALS

Recent evidence suggests more clearly that the intra-seasonal variability of the atmospheric circulation in the North Atlantic, and in particular the North Atlantic Oscillation (NAO), is impacted by tropical convection related to the phase of the Madden-Julian Oscillation (Cassou 2008; Lin et al. 2009). The long-term goals of this project include:

(1) Understanding more clearly the mechanisms that mediate the tropical-NAO connection in nature.

(2) Assessing the prospects for utilizing this source of tropical predictability to improve dynamical forecasts of the North Atlantic intra-seasonal variations within a seamless prediction system.

OBJECTIVES

(1) Assess the "perfect model" (idealized) predictability of the NAO at forecast ranges from 1-45 days in the Community Earth System Model (CESM) of NCAR and possibly the Coupled Forecast System Model (CFSv2) of NOAA.

(2) To make predictions of observed NAO events at ranges of 1-45 days using CESM and CFSv2.

(3) To assess the changes in the predictability and prediction skill when realistic MJO-related tropical diabatic heating is added to the models.

(4) To diagnose the dynamical mechanisms by which the tropical heating variations affect the North Atlantic.

Report Documentation Page

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APPROACH

In order to gauge the impact of the MJO on the North Atlantic variability, MJO-related tropical diababtic heating derived from TRMM satellite data is added to the CESM as it runs: at each time step the four-dimensional (time varying) MJO-heating is added to the temperature tendencies produced by the model's dynamics and physical parameterization subroutines before these tendencies are used to update the temperature field. This techique has been used in the seasonal mean context by Jang and Straus (2012, 2013). Large ensembles of seasonal simulations (1 Oct – 31 Mar) made with ("HTG " simulations) and without ("CTL" simulations) the added heating are used to assess the effect on the NAO. The first HTG experiment has the MJO-heating identical for each winter simulation, following several MJO episodes whose properties (e.g. dependence on the annual cycle evolution) are derived from observations. The second HTG experiment will have the MJO heating vary from simulation to simulation, again using observational statistics as a guide.

To compute idealized predictability in each experiment, we employ ensembles of short-range forecasts that are initiated n-days prior to peaks in the NAO principal component (where n goes from 5 to 45), with small perturbations added to the initial conditions. Real forecasts of observed NAO events will involve initializing the CESM (or CFSv2) model with observed atmospheric initial conditions (plus perturbations). Versions of these intra-seasonal forecasts with and without MJO heating will be constructed.

Key individuals and the roles they play are given here:

David . Straus (GMU): Supervises design and execution of project; carries out diagnoses of all results.

J. Shukla (GMU): Aids in overall project planning.

Priyanka Yadav and Sara Amini (GMU): Diagnosis of model experiments

Cara-Lynn Lappen (Texas A&M): Design of TRMM-based added satellite heating

Erik Swenson (APCC, Korea): Help in running CESM.

WORK COMPLETED

The work proposed for the first year of the project has been completed. We ran the CTL experiment of 50 CESM simulations (1 Oct – 31 Mar) using initial conditions from a long 50-year control simulation. The first HTG experiment, in which the same evolution of the MJO additional heating was added to each of the 50 simulations, has also been completed. Figure 1 shows the 50-member ensemble mean of the 500 hPa diabatic heating (averaged from 10S-10N) produced by the model dynamics and physics in the colored contours for the HTG (CTL) experiment in the left (right) panel, with a contour interval of 2 ^{o}C/day. Separately, the added MJO diabatic heating is shown in black contours in the left panel with a contour interval of 0.5 ^{o}C/day. (In the HTG experiment, it is the sum of the two heatings that the model uses in the thermodynamic equation). The results clearly show that added heating (identical for each member of the ensemble) has organized the model produced heating to produce clear MJO episodes. Note that the "box-like" appearance of the added heating is due to the necessity of adding the heating as 10-day means rather than daily values. This is due to technical difficulties encoutered with the atmospheric GCM code in CESM.

Principal component analysis was carried out for the 1 Dec- 31 Mar portions of both the CTL and HTG simulations using 850 hPa heights. This was carried out for both the North Atlantic and Pacific-North America sectors, for both 10-day means and daily fields. (The principal component analyses based on 10-day means give results that are nearly identical to those using daily data.) Figure 2 shows the composites of 500 hPa height anomalies, based on the condition that the principal component exceeds one standard devation.

There is a fairly clear correspondence of these patterns and the three clusters identified by Cassou (2008), namely the NAO+, theScandinavian Blocking and the Atlantic Ridge patterns. (The distinction between the NAO+ and the negative of the NAO- cluster patterns is of course lost when using principal components, which is a linear analysis.) The corresponding patterns for the CTL experiment are very similar.

RESULTS

The HTG experiment clearly shows that technique of adding time-dependent heating to the CESM is successful in the sense that the model continues to run, the added heating successfully organizes the model heating to produce MJO-like episodes, and the vertically integrated net heating difference between the HTG (including the added heating) and CTL is very small (not shown). This is in part due to the partial compensation between the added heating and the model-produced heating in the HTG run; the added heating induces extra vertical motion and convection, and hence added radiative cooling. The results ensure that we have a valuable tool that can be applied for the remainder of the project.

While the MJO heating does not radically change the nature of the NAO intra-seasonal variability (the leading principal component composites of CTL and HTG are quite similar), Figure 3 shows that the NAO variability in the HTG experiment is organized by the MJO. The left hand panel shows the heating for the HTG run (as in Figure 1) for the Dec-Mar time frame. The right hand panel shows the ensemble mean of the leading principal component (normalized to unit standard deviation). Since the same additional MJO heating evolution has been applied to each run, we expect that the resulting daily evolution of the ensemble-averaged NAO should at least partially reflect the MJO heating. From Figure 3 one can see that roughly 10-15 days after the convection peaks in the Indian Ocean, the phase of the NAO with the enhanced high-latitude low (enhanced Atlantic jet), here called the NAO+ becomes significantly positive. This agrees with the observationally based analysis of Cassou (2008), carried out using a multi-variate principal component analysis for the MJO and a cluster analysis for 500 hPa heights.

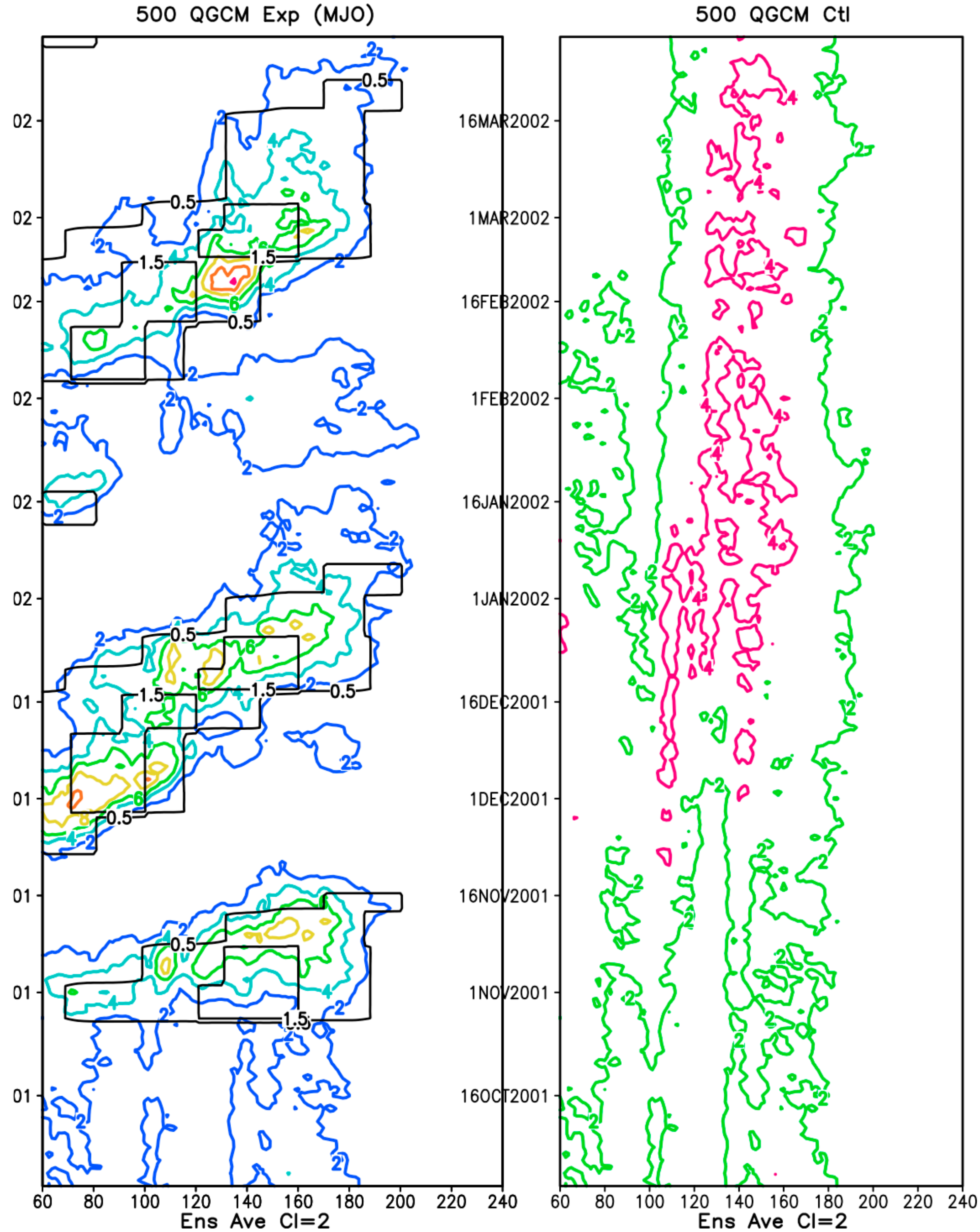

Figure 1. 50-member ensemble mean of the 500 hPa diabatic heating (averaged from 10S-10N) from the model dynamics and physics in the colored contours for the HTG (CTL) experiment in the left (right) panel, with a contour interval of 2 ^{o}C/day. Separately, the added MJO diabatic heating in the HTG experiment is shown in black contours in the left panel with a contour interval of 0.5 ^{o}C/day

The relationship between the NAO+ and Indian Ocean convection on intra-seasonal time scales is also seen from lag compositing of the 200 hPa velocity potential field based on the NAO principal components. Figure 4 shows the velocity potential averaged about the equator (10S-10N) composited for various lags, based on the condition that the NAO principal component exceeds one standard deviation. For negative lags of up to 15 days (velocity potential leading the NAO), a clear indication of convection (upper level outflow) is seen. While this is also the case for the CTL run (not shown), the strength of the velocity potential gradient is twice as large in the HTG run, indicating a stronger connection.

Analysis of the Pacific – North American region principal components and their relationship with tropical convection has also been carried out. The lag composite of western and central Pacific Ocean convection (seen through the equatorial velocity potential) shows that strong upper level outflow leads the leading principal component (not shown) in the HTG experiment, and that this occurs to a much greater extent than in the CTL experiment. The excitement of the wave train associated the leading principal component is thus the first step in the influence of the MJO on the extra-tropical circulation.

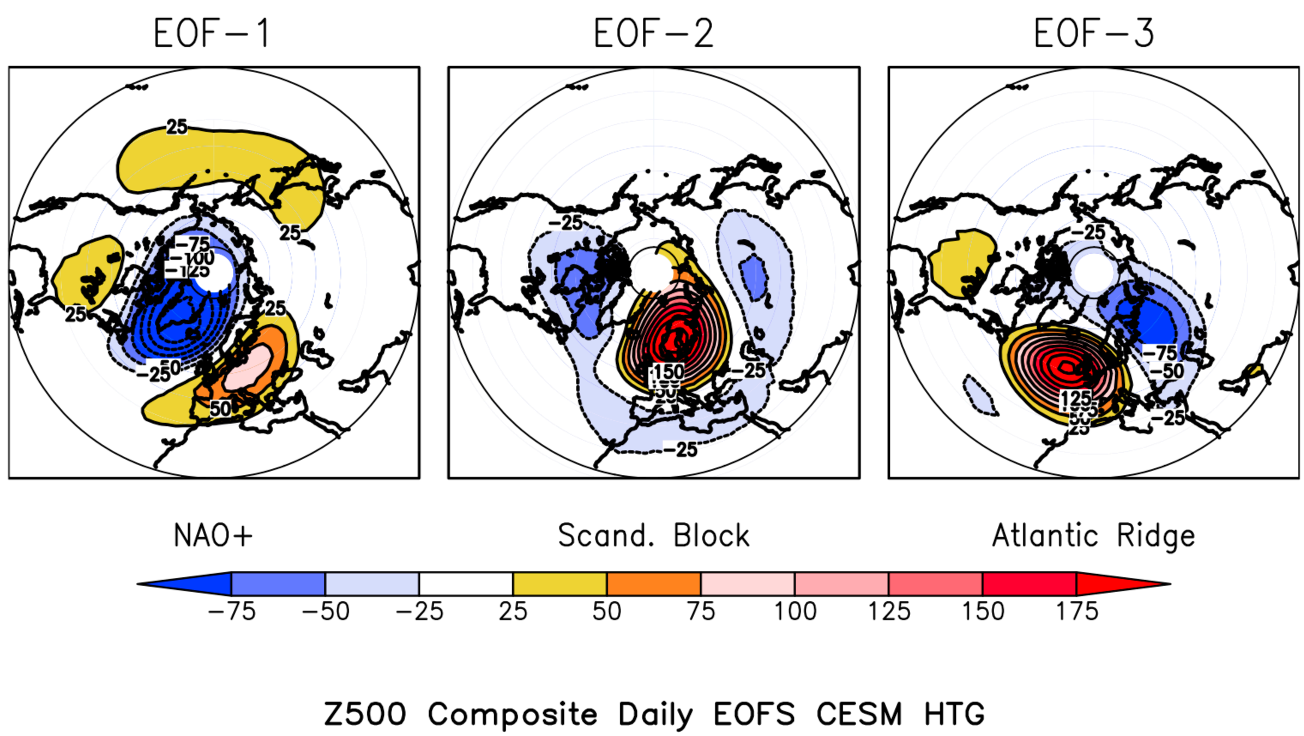

Figure 2. 500 hPa composites (in m) based on the leading three princpiple components of daily 850 hPa heights in the North Atlantic region. The composites are averages over all days when the principle component exceeded one standard deviation. The pattern labels correspond to the analagous patterns derived from observations from Cassou (2008).

IMPACT/APPLICATIONS

Our results clearly indicate that the technique of adding intra-seasonally varying diabatic heating to a state-of-the-art coupled weather/climate model is feasible, and can lead to validation of hypotheses made from observations, in this case the effects of intra-seasonal tropical heating variability on NAO variability. Since models are known to have a number of difficulties in simulating the MJO and other intra-seasonal oscilattions, we expect the this technique will see a productive use in other scientific studies.

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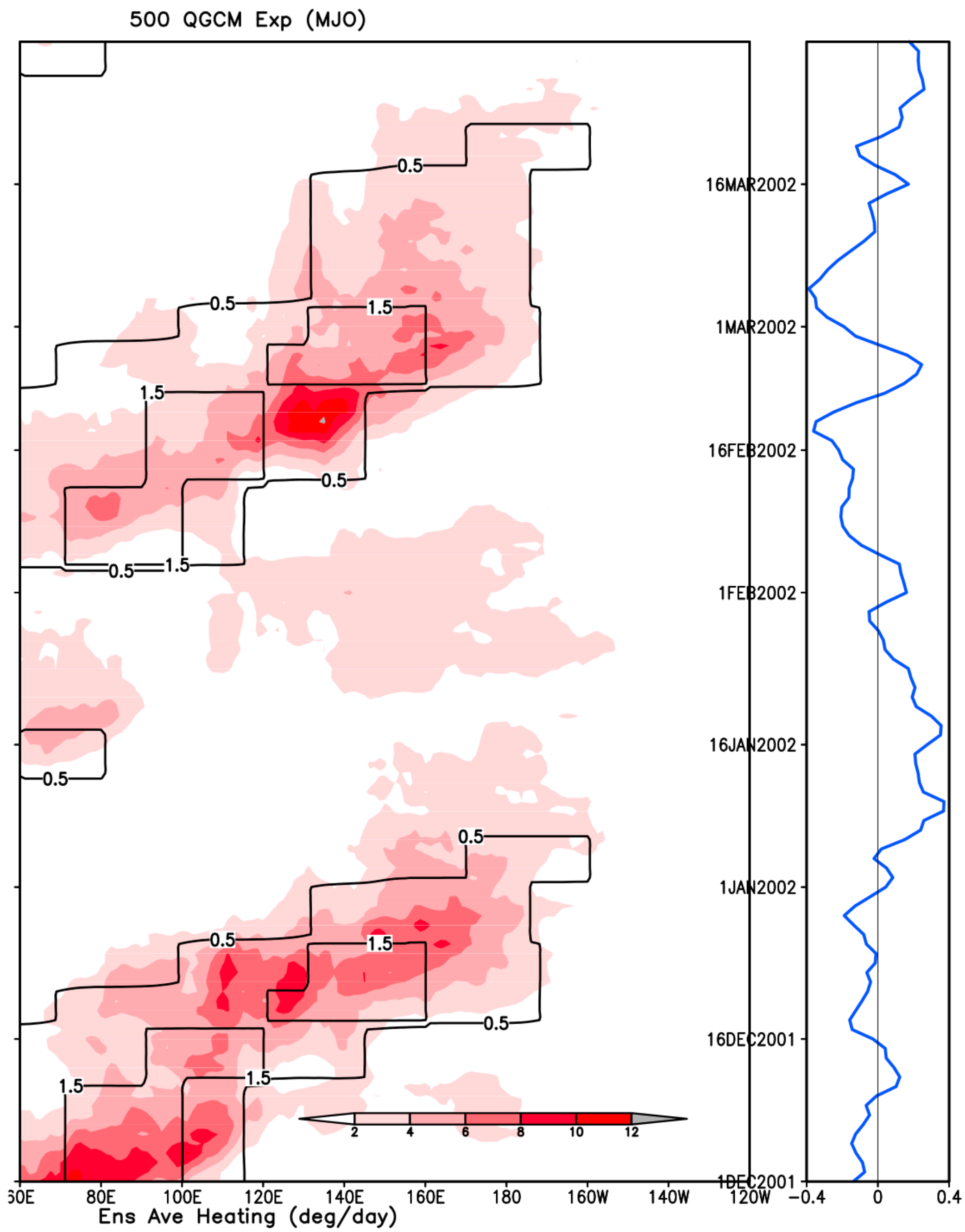

Figure 3 Left panel shows ensemble average model heating at 500 hPa for HTG experiment (shading), and the added MJO heating (see Figure 1) for the 1 Dec – 31 Mar period. Right panel shows the principal component associated with the NAO pattern shown in Figure 2, normalized to have unit variance.

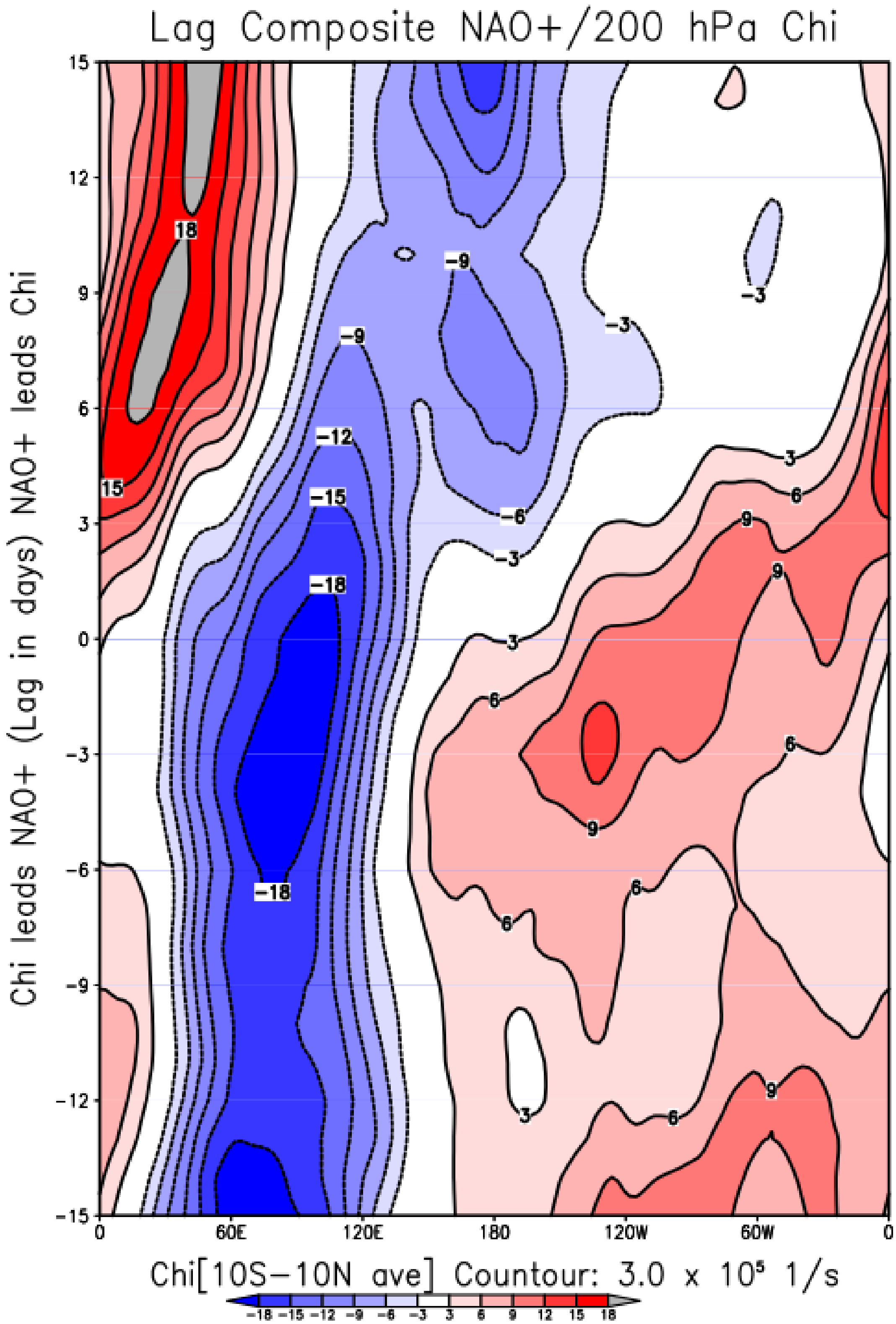

Figure 4. Lag composite of 200 hPa velocity potential averaged near the equator (10S-10N), based on the leading prinicple component (PC) of the NAO+ pattern shown in Figure 2. Composite based on time when PC exceeded one standard deviation. Velocity potential contour is 3 x 10^5 s^{-1}. Negative lags means velocity potential leads NAO+ occurrence.